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The potential application of overhead reconnaissance techniques to crop estimation.

AERIAL PHOTOGRAPHY FOR AGRICULTURE

William R. Gasser

Aerial photography has been used in the United States for several decades to obtain useful information on agricultural resources, and in recent years intelligence analysts have taken increasing advantage of it for help in estimating crops and identifying trouble spots in the agricultural sector of Communist countries. As a source of intelligence on the agriculture of a foreign power it is still in its infancy, but it shows promise of becoming a valuable aid.

Stagnation in Communist Agriculture

Communist leaders have revealed an increasing awareness that the provision of an adequate supply of food is one of their most critical problems. In nearly all Communist countries stagnation in agriculture has seriously damped economic growth. Because of this stagnation in the face of continued increases in population, they have had to spend an average of more than $1 billion annually during recent years to purchase grain from the West, while by way of contrast the United States earns about $2 billion annually from sales of grain abroad. These purchases of grain have placed a severe strain on Communist reserves of gold and foreign exchange. For the USSR and particularly China, grain imports have meant a sacrifice in the acquisition of badly needed machinery and equipment.

The Communist leaders now realize that agriculture must be accorded a higher priority than in the past, even though this may require some diversion of investment funds from defense and heavy industry, the traditional priority sectors. Emphasis is being given to agricultural intensification—getting higher yields per acre. Increased supplies of mineral fertilizers, pesticides, and improved seeds have been promised, along with expanded irrigation and higher incentives for farm workers and managers. The USSR's record crops in 1966 reflect in part this greater priority. But to what extent the Communist effort can mitigate the serious agricultural problems that stem

largely from the nature of the system remains a critical question before the economic intelligence analyst.

Crop Estimation Procedures

The analyst attempting to evaluate the current agricultural situation in the Communist countries has a very difficult task. Inadequate sources of information make the estimating process much less refined than he would like. He is envious of the U.S. Department of Agriculture's Statistical Reporting Service, which in estimating U.S. crop production has available the periodic returns from more than 850,000 volunteer crop and livestock reporters scattered throughout the country. He himself has to build up his estimate of the early summer condition or the final harvest of a Communist crop from scattered bits and pieces of evidence.

In trying to determine, say, the actual amount of grain harvested in the Soviet Union in a given year he begins with an estimate of sown acreage by region and by kind of grain. Yields per sown acre by crop are estimated from widely variant sources—detailed weather information provided by the U.S. Air Force, reports from the press and Western travelers describing the condition of the crop at various times during the season, the reported progress in seeding and harvesting, data on grain procurement in various administrative subdivisions, general statements made by Soviet officials, data on inputs such as machinery, fertilizer, and seed. These estimated yields per acre are checked against the figures obtained for earlier years when crop and weather conditions were similar in the respective regions. Then they are multiplied by the estimated sown acreage to give the production of each kind of grain and the total grain harvest.

In the past few years aerial photography has become an important new source in this process, primarily, thus far, as applied to China and North Vietnam. Here its supporting role has been considerable because of the paucity of data on these countries. In the early 1960's U-2 photography over China partially filled the almost complete vacuum of information on agricultural production. During the spring of 1963, for example, weather information and Chinese press and radio reports indicated the possibility of a rather severe drought in south China. Chance availability of U-2 photography over south and central China at various times from January to June provided confirmation in the form of dried-up river beds and reservoirs as far north as Hunan province. Similarly, in the late summer and autumn

of 1963 the Chinese press and travelers reported severe flooding in the north China plain. Weather data also showed above-average rainfall for the period March-July, followed by very heavy rains over large areas in the first ten days of August—up to 18 inches in the area of maximum precipitation. U-2 photography in September and October 1963 revealed that large areas of the plain were still covered by water.

More basically than in this verification of moisture conditions affecting crop production, the photography of North Vietnam and China has been valuable for purposes of familiarization with agricultural processes and projects in the two countries. From reconnaissance photography over North Vietnam the photointerpreters have been able to tell what state of preparation fields are in for rice culture and then the crop's stage of maturity—from seedlings to fully mature rice being harvested. A number of farming operations such as plowing, transplanting, and harvesting were readily identified. It has also been possible to spot certain conditions that, depending on severity and time of occurrence, could significantly affect crop yields, such as lodging (grain flattened by wind or rain) and flooding. Photography of China has been particularly helpful in evaluating the success of programs to reclaim land and develop irrigation. Large areas of reclaimed land in northern Heilungkiang province appeared to have been abandoned. In other areas, particularly in the north, many canals dug during the Leap Forward were subsequently refilled and the land returned to cultivation.

Potential Refinement

Experts in the development of remote-sensing devices believe that satellite-mounted remote sensors have great potential as an aid to estimating crop production worldwide. Wernher von Braun, asked about the possibility of directing some of the "technological spin-off" from our moon program toward solving the world's hunger problem, replied:

> It has been demonstrated with airplane flights, using some sophisticated photographic equipment and remote sensors, that from high altitudes you can distinguish very clearly rye from barley, soybeans from oats. Moreover, you can distinguish healthy crops from sick ones. You can, for example, distinguish corn afflicted by black stain rust from healthy corn. You can also find out whether the proper fertilizer has been applied, whether there is too much salinity in the soil.

> By continuously surveying and re-surveying the tilled areas of the world—by keeping track of each patch of land as it develops from the planting season in the spring to the harvesting season in the autumn—you can predict very well the crop expectations on a global scale. When drought hits an area, you will find a local setback. If some crop has been damaged or destroyed by hail, your satellite-mounted remote sensors will find it.
>
> As you get closer to the harvesting period you can, by feeding all that information into a computer, predict just how much of a crop to expect, and what kind, and when and where.
>
> Of course, you would need plenty of correlation data before the data produced by such a satellite system would be reliable. You get this correlation simply by comparing the "ground truth," or the facts determined by a man walking through a field, with what the satellite equipment sees in that same field.[1]

Well in advance of this suggestion from Von Braun, CIA's research and development organization had begun intensive investigations of the feasibility of determining yields of rice, wheat, and sugar cane from high-altitude photography, and the preliminary results were affirmative.[2] Flights were made with cameras of such focal lengths as to simulate from several conventional altitudes the corresponding high-altitude scales. A few flights were made at U-2 altitudes for purposes of correlation. Photography was also taken from a 150-foot tower to permit large-scale sequential photography of test crops planted adjacent to the tower. Various filters were tried in combination with black-and-white, color, and infrared film. Ektachrome infrared seemed best for rapid monitoring of a crop's health, but once yield-reducing factors were suspected the black-and-white was better able to discriminate among these factors.

In these investigations a preliminary photointerpretation to establish parameters was conducted during the early stages of each crop, and then its further growth was followed by photointerpretation at various stages. The procedure used in estimating yield was to estimate degradation from a theoretical maximum potential yield. It was assumed that, given seed typical of the variety grown with success in the study area and a suitable plot of ground, a perfect crop of known yield would result except for the action of yield-limiting factors which may become operative from the day the seed is sown. These degrading factors

[1] *U.S. News and World Report*, 12 Dec. 66, p. 66.

[2] "Investigation on the Feasibility of Determining Yield of Rice, Wheat and Sugar Cane by Means of High Altitude Aerial Photography," Vols. I, II, and III, Final Report ORD #2265-66.

may be classified as physical, that is the absence of crop-producing plants in any part of the field or less than ideal plant density, or physiological—pests, disease, drought, or other operants against the vigor and hence the yield of the plants. These factors may affect yield in decidedly different ways depending upon the severity of their manifestation and the stage of growth at which they appear.

Statistical analyses were performed on the results of the photointerpretation as the yield estimates so reached were correlated with ground-truth yields obtained after harvest. Sources of error were evaluated with respect to each of the photographic scales, film-filter combinations, and photo dates. It was found that a number of the yield-reducing factors—disease, insects, weeds, drought, flood, winterkill, mineral deficiencies, toxicities—can be assessed on aerial photography. For an accurate assessment of the degree to which these will affect yields, however, the photography must be taken according to specifications tailored to each factor so as to detect the extent and severity of its manifestations. It must be taken in the spectral bands that give the best tone values for the factor in question. It must also be taken at the right times during the growing season.

The contractor who carried out this investigation is testing the technique on a larger scale during the 1967 growing season by undertaking to estimate the yield per acre and total production of wheat for the state of North Dakota.[3] North Dakota, the leading U.S. spring-wheat-producing state, is in many ways climatically analogous to the new lands area of the USSR. A five-mission schedule with U-2 aircraft was carried out during the June-September period, each mission making three north-south flights across the state. The photography, taken by multispectral filtration, is still undergoing analysis at time of writing.

One of the difficulties in analyzing the output of photographic reconnaissance is the tremendous volume of imagery that must be scanned. The problem becomes particularly acute when the target is agricultural production, with scattered fields of different types of crops covering hundreds of square miles. Its solution may lie in sophisticated sampling procedures, or in a high degree of automation in the interpretation of the photography, or in a combination of both. An ultimate goal is the development of remote sensing systems that require little or no human participation to reduce their raw data to the

[3] "Technical Proposal for 1967 Chitter Program." ORD #570-67.

desired end information. One system now under investigation records the relative amplitude of spectral components of the radiation emanating from a source and applies automatic pattern recognition techniques to identify designated characteristics so revealed. This research, now under way at Purdue University under U.S. Department of Agriculture and NASA contracts, assumes that various crops can be differentiated on the basis of multispectral response "signatures" at various times during the growing season and that for any particular crop it will be possible to determine what variations in the response signatures are caused by yield-influencing factors and so distinguish these. In initial tests the computer output provided a good reproduction of a strip of Indiana farmland one mile wide and five miles long, plotting the major vegetative patterns on it. The operational stage of automated scanning and data reduction is unlikely to be "just around the corner," however.

Outlook

The results of developmental research to date in aerial photo estimation of crop yields make it seem likely that this technique will become an increasingly important tool for the intelligence analyst estimating Communist agricultural production. For the foreseeable future, however, it will probably supplement rather than replace present methods. And pending further development and refinement of techniques for computerized estimation from photographic patterns, the intelligence community will continue to rely on the skills of specialists in photointerpretation for qualitative evaluation of agricultural conditions in problem areas where photo coverage is available.